INNOVATIONS IN SCIENCE EDUCATION AND TECHNOLOGY

Series Editor:
Karen C. Cohen, Harvard University, Cambridge, Massachusetts

Are Schools Really Like This?: Factors Affecting Teacher Attitude toward School Improvement
J. Gary Lilyquist

Education for a Sustainable Future: A Paradigm of Hope for the 21st Century
Edited by Keith A. Wheeler and Anne Perraca Bijur

The Hidden Curriculum—Faculty-Made Tests in Science
Part 1: Lower-Division Courses
Part 2: Upper-Division Courses
Sheila Tobias and Jacqueline Raphael

Internet Links for Science Education: Student–Scientist Partnerships
Edited by Karen C. Cohen

Place of Science in a World of Values and Facts
Loucas G. Christophorou

Portable Technologies: Science Learning in Context
Edited by Robert F. Tinker and Joseph S. Krajcik

Science, Technology, and Society: A Sourcebook on Research and Practice
Edited by David D. Kumar and Daryl E. Chubin

Technology, Science Teaching, and Literacy: A Century of Growth
Kenneth P. King

Time for Science Education
Michael R. Matthews

Tutorial Distance Learning: Rebuilding Our Educational System
Alfred Bork and Sigrun Gunnarsdottir

Web-Teaching: A Guide to Designing Interactive Teaching for the World Wide Web, Second Edition
David W. Brooks, Diane E. Nolan, and Susan M. Gallagher

A Continuation Order Plan is available for this series. A continuation order will bring delivery of each new volume immediately upon publication. Volumes are billed only upon actual shipment. For further information please contact the publisher.

Portable Technologies

Science Learning in Context

Edited by

Robert F. Tinker
The Concord Consortium
Concord, Massachusetts

Joseph S. Krajcik
University of Michigan
Ann Arbor, Michigan

Kluwer Academic/Plenum Publishers
New York, Boston, Dordrecht, London, Moscow

Metz, K.E. 1995. "Reassessment of developmental constraints on children's science instruction." *Review of Educational Research*, 65:93–128.
Mokros, J.R. and R.F. Tinker. 1987. "The impact of microcomputer-based labs on children's ability to interpret graphs." *Journal of Research in Science Teaching*, 24(4):369–383.
National Research Council. 1996. *National Science Education Standards*. Washington, DC: National Academy Press.
Osborne, R. and P. Freyberg. 1986. *Learning in Science: The Implications of Children's Science*. London: Heinemann.
Perkins, D. 1986. *Knowledge as Design*. Hillsdale, NJ: Lawrence Erlbaum Associates.
Perkins, D., D. Crismond, R. Simmons, and C. Unger. 1995. "Inside understanding" in D. Perkins, J. Schwartz, M. West, M. Wiske, eds., *Software Goes To School: Teaching for Understanding With New Technologies*. New York: Oxford University Press.
Resnick, L.B. 1987. "The 1987 Presidential Address: Learning in school and out." *Educational Researcher*, 19(7):10–18.
Roth, W.M. 1995. *Authentic School Science*. Dordrecht, The Netherlands: Kluwer.
Rutherford, F.J. and A. Ahlgren. 1990. *Science for all Americas*. New York: Oxford University Press.
Shapiro, B. 1994. *What Children Bring to Light: A Constructivist Perspective on Children's Learning in Science*. New York: Teachers College Press.
Talsma, V. 1998. "Student scientific understandings in a ninth grade project-based science classroom: A river runs through it." Unpublished Dissertation, Ann Arbor: University of Michigan.
Tinker, R. 1991. "Thinking about science." Unpublished manuscript, Technical Educational Research Center, Cambridge, MA.
White, B.Y. 1998. "Computer microworlds and scientific inquiry" in M.C. Linn, ed., *International Handbook of Science Education*. Dordrecht, The Netherlands: Kluwer.
White, R.T. 1998. *Learning Science*. Oxford: Blackwell.
Whitehead, A. 1929. *The Aims of Education*. New York: Macmillan.

CHAPTER 2

Incorporating Portable Technology to Enhance an Inquiry, Project-Based Middle School Science Classroom

Ann M. Novak and Christine I. Gleason

INTRODUCTION

How do you help students develop science concepts through the process of inquiry? How can students engage in authentic investigations that make science meaningful and interesting? What role can the teacher play to help foster a student's understanding of science concepts and science process? How can incorporating new technology tools enhance student learning?

As teachers we strive to help our students develop an in-depth and integrated understanding of science concepts and process skills. We also use technology tools, where appropriate, to help promote these goals. In this chapter we describe how we have incorporated portable technology to enhance a seventh grade project on water quality. We begin by providing

Ann M. Novak and Christine I. Gleason, Greenhills School, Ann Arbor, Michigan

Portable Technologies: Science Learning in Context, edited by Tinker and Krajcik. Kluwer Academic/Plenum Publishers, New York, 2001.

some background about us. We then give an overview of our program. This is followed by a description of the water project, an overview of the curriculum we have developed for this project, and the implications of portable technology for curriculum development in general. We finish with a discussion of the benefits of portable technology for student learning and for teachers and some challenges presented by the use of portable technology.

WHO ARE WE?

We teach seventh and eighth grade science at Greenhills School, an independent school in Ann Arbor, Michigan. Ours is a sixth to twelfth grade school with a student enrollment of about seventy-five students per grade. Greenhills School is not a school for gifted students, but it does have an admissions process that generally includes accepting students from the upper two-thirds of standardized test norms. We have between sixteen and twenty-two students per class. We each teach two classes of seventh grade and two classes of eighth grade science. Chris has taught for twenty-seven years, has a bachelor of science degree with a major in biology, a minor in chemistry, a master's in special education, and a 7-12 teaching certificate. Ann has taught for eight years, has a bachelor of science degree with a major in broad field science, a minor in biology and health, a master's in adolescent development, and a 7-12 teaching certificate. Six years ago we began to develop a project-based approach to teaching and attended project-based institutes at the University of Michigan. We continued to attend work sessions during the next several years. As teachers we collaborate closely to develop curriculum and to enhance our curriculum by incorporating technology tools where appropriate. We were chosen as a test site for Science Learning in Context by the Concord Consortium and the University of Michigan, in part because of our project-based approach and because of our desire to incorporate technology into our curriculum. Prior to beginning the implementation, we learned to use the portable technology and probeware and attended an intensive three-week summer workshop at the Concord Consortium in Massachusetts.

OUR SEVENTH GRADE SCIENCE PROGRAM

The goal of our science program focuses on facilitating students to develop in-depth and integrated understandings of fundamental science concepts and science process skills within the context of inquiry. Using a project-based approach, several units are explored each year that incorporate science across several disciplines. We structure our classrooms so that students ask important and meaningful questions and use technology tools

Figure 2.1. Akin collects temperature data and records observations (photo by Mijo Pappas).

to investigate these questions (Krajcik 1993; Blumenfeld et al. 1991). Each unit begins with a "driving question" (Krajcik, Czerniak & Berger 1999) that provides students with a real-life context. Our students engage in inquiry through activities that investigate the driving question and related sub-questions. Learners find solutions to these questions through engagement in long-term investigations and collaboration with others. In the process they develop in-depth and integrated understanding of science concepts and process skills. By this we mean our students "see relationships among ideas, to find underlying reasons for these relationships, to use these ideas to explain and predict phenomena, and to apply their understandings to new situations" (Krajcik et al. 1999). We also believe our students become better thinkers and problem-solvers. This approach is consistent with the *National Science Education Standards* (NRC 1996) and with the American Association for the Advancement of Science (1993) *Benchmarks for Science Literacy*.

Our program is based on inquiry. However, getting our students to be scientists initially takes much support from us. This is the first time most of our students have been exposed to extended inquiry where they collect and synthesize data over time. We help our students learn the process of inquiry through teacher-designed investigations and activities that model the process. They learn to ask good questions and research pertinent background information using a variety of resources (library and Internet, experts in the community, science books, and teacher handouts). They

Figure 2.2. Emily and Ellen collect fall pH samples.

develop sound predictions based on this research and learn the importance of creating a procedure that controls variables and carefully addresses the question to be studied. Students are introduced to several data collection and analysis techniques that incorporate appropriate technology tools. We support students as they look for patterns and relationships in their data. After logical and critical reflection of all the information important to providing an answer to their question, students also gain experience in drawing conclusions. They share this information with each other throughout the process and present their findings at the end of the investigation. The process of inquiry, they learn, often leads to new questions.

Although it is a collaborative process, the project incorporates individual components as well. Students work together during much of the process, including data collection. They share their ideas about predictions, but each student writes his or her own. After teams collect data and discuss and analyze the results, each student writes up her or his own analysis. This allows us, as teachers, to gain insight into each student's understanding of concepts and process. It also helps to ensure each student's investment in the investigation. As students gain experience in the process of inquiry, there is a transition from mainly teacher-designed investigations to a combination of teacher- and student-designed investigations. Through careful scaffolding, students proceed to asking their own sub-questions. They research background information and design and conduct an investigation incorporating the technology tools that will aid them in their

investigation. This methodology reflects the project-based model proposed by Krajcik and colleagues (Krajcik et al. 1998, 1999).

OUR WATER PROJECT: OVERVIEW

During each of three seasons (fall, winter, and spring) seventh grade students investigate a nearby stream by asking the question, "How clean is the water behind our school?". Student groups design and carry out a plan to investigate their adopted portion of the stream. Using portable technology as scientific instruments, students collect and analyze various quantitative water-quality data along with qualitative data to make conclusions about the health of the stream. We use benchmark lessons to introduce students to key ideas, including science concepts, technology tools, the process of inquiry, and collaboration. Students also create products, or artifacts, that represent their learning.

The goal of investigating "How clean is the water behind our school?" is to allow students to develop an understanding of concepts in chemistry, earth science, and ecology through the process of inquiry. Some of the concepts include: watershed, water cycle, water quality, water-quality testing, point and non-point source pollution, pH, solutions/non-solutions, eutrophication, density, and topography. We also help students develop scientific process skills. They collect qualitative and quantitative data, create graphs to aid them in their analysis, and look for patterns in their data to

Figure 2.3. Arielle and Katie collect spring dissolved oxygen data.

help explain their findings. To accomplish these goals we include technologies that will support and enhance "understanding scientific concepts and developing abilities of inquiry" (NRC 1996). It is our belief that the curriculum must incorporate the learning technology tools as just that: *tools* that truly enhance student learning of science concepts and science process rather than as technology for technology's sake.[1] Learning technologies allow students to undertake aspects of inquiry that they could not otherwise do. In order to achieve these goals we develop curriculum that is consistent with our inquiry, project-based approach to teaching and also entails appropriate use of technology tools.

CURRICULUM DEVELOPMENT

In this section we discuss some of the curriculum materials that we developed for our water unit using a project-based approach in which portable learning technology is integral to what students do.

Contextualization

A stream meanders through the school property about fifty meters from our building. This small stream runs into a larger stream that flows into the Huron River, a major source of drinking water for our community and many communities in the surrounding area. Our school watershed is part of many of our students' neighborhood, with some of our students living in condominiums that directly adjoin the stream. For these reasons, "How clean is the water behind our school?" is a driving question important in the context of students' lives.

To further contextualize this question, we take students for a stream walk early in the year so that they become familiar with the stream and the area near it that could impact its quality. Students record observations about anything they see, hear, or smell during the stream walk. They see many plant varieties. They hear and see birds and other wildlife. They hear cars on a nearby freeway. They see nearby condominiums, streets, our school, and its parking lot. They see a pond near the stream on our school's property, with several pipes that lead both into and out of it. They also see several storm drains in the parking lot as well as one behind the condominiums near the beginning of the stream. Upon seeing the pipes students often ask their purpose, especially in regard to their potential impact on the stream. Students share their observations later in class, categorizing their observations into one of three groups: biological world, geological world, or social world. This connects nicely into our driving question and prompts students to begin thinking about various factors that may lead to clean or polluted water.

[1] When technology is used as a tool to promote learning we refer to this as a learning technology (Krajcik, Blumenfeld, Marx & Soloway 1999). Other phrases such as technology tools, portable technology, and new technologies are also used.

The stream walk not only familiarizes students with the stream but it leads to two sub-questions: "Where does the stream water come from?" and "What are the pipes for?". This leads us to seek out an "expert" who will provide insight to these questions. Our guest speaker,[2] one of our school administrators who started out as a teacher thirty years ago when the school was built, provides our students with a historical overview. Our small school was built on top of a hill that was once farmland with a dirt road leading to it. "When we looked out the school window the only thing we saw was a barn, a large oak tree, and farmland. ... The stream did not exist," our speaker says. He provides students with a progression of the neighborhood build-up, including school expansions, the condominiums, roads, etc. He also discusses the creation of a pipe system built under and around the school to capture water and channel it to a holding pond so it can slowly filter into the human-made ditch (our stream) to eventually run into the Huron River. He provides students with blueprints so they can visualize the process. The condominiums, he explains, have similar pipes that carry surface water to drainage pipes that flow into the stream. These, as well as pipes from the parking lot and the nearby roads, are the source of the stream water. Our human-made ditch flows with water twelve months a year and is now charted as a stream by the state of Michigan.

Students now have a meaningful context for science learning. The driving question with sub-questions, the stream walk, and the expert guest speaker create a rich context for students to develop science concepts and science process around the project of water quality. Before students scatter along various sections of the stream to investigate its water quality, they need to develop good understandings of the science concepts, the process of inquiry, and the use of the technology. Developing these understandings allows students to investigate the stream and analyze their findings to make informed decisions about its quality. These understandings, for the most part, can be gained within the smaller setting of a classroom. Through benchmark lessons students gain an understanding central for exploring the question.

Benchmark lessons

Several benchmark lessons lay the foundation for student work. "Benchmark lessons are teacher-directed classroom activities that present

[2] Special thanks to Bill Reish for sharing his expertise and time with our students.

concepts, principles, or skills that students need in order to understand the work of the project" (Krajcik et al. 1999). These experiences help students construct the science concepts, give them experience with scientific inquiry, and at the same time provide them with experience and practice using the portable technology.

We begin with benchmark lessons that investigate "Just how much water is on earth and how much of that is usable?" and "Where does water come from?". To investigate these sub-questions, students learn about the water cycle and create a model of a watershed. Topography activities complement these initial activities. Students look at actual topographical maps that include the neighborhood of the school as well as the stream.

We have a simple but powerful story[3] that serves as the springboard for a series of mini-experiments as students investigate other sub-questions, such as "How is water polluted?" and "How do we judge water quality?". These mini-experiments introduce the water concepts with activities that simultaneously introduce the portable technology tools. Students use probes attached to handheld computers to measure temperature, pH, dissolved oxygen, and other data. The computers act as portable laboratories that allow students to collect and analyze data on site. As part of these activities students learn the procedural steps necessary to successfully use the portable technologies. These activities begin with teacher-designed investigations and transition to student-designed investigations.

In the story, Sally, a small, plastic fish, must swim upstream to lay her eggs. In this story Sally's stream winds through farms, a town, a park, and a small lake surrounded by homes. As the teacher reads the story to the students, he or she also reads of substances that have entered the water (it's raining) as Sally passes each point. Salt from the roads, leaking motor oil, acid from acid rain, fertilized soil, waste from a treatment plant, and litter are some of the substances that the teacher adds to a fish tank. With the addition of each new substance, students respond with written reflections. Once Sally reaches her destination students are asked to "finish the story." Although no mention is made of specific terminology, students are introduced to most of the concepts through this story. We save Sally's water for later use when students design and build water purification systems to see who can best clean Sally's water.

Based on Sally's story and their own experiences, students generate a list of possible substances that could enter into water (fertilizers, soap from car washes, soil, acid rain, oil, etc.). Using this information students create ten to fifteen containers of "polluted water" solutions. This leads students to read and learn about the various substances (developing background knowledge) and then to ask, "How can we test the substances and know

[3] "Sally's Upstream Journey: A Story of Man's Effect on Water Quality" (Author unknown).

what they will do to the water and the life in and around it?". We say, "We have some tools that will give us valuable information about the substances!".

The "need to know" brings students to the technology. Technology provides them with instrumentation[4] to collect data and further pushes them to "need to know more" about what the information means. Initially we provide students with activities that introduce a particular probe. By using the probe, they learn concepts associated with the information. Each activity begins with a sub-question and includes students making predictions. To provide a foundation for data analysis we use class activities, whole group discussions, and readings. Students use *Water Quality Studies for Younger Folks: A Water Activities Manual for 5th through 8th Grades* (Cromwell et al. 1992) as a primary resource for background information about the test and what it means for water quality. They also begin to write background information to coincide with each of the activities as it relates to the stream quality. This information will later be included in their stream study. *The Field Manual for Global Low-Cost Water Quality Monitoring* (Stapp & Mitchell 1995) provides students with water-quality standards. Students follow or design a procedure, collect and analyze data, and develop explanations that they share with each other. For example, our students test all of the substances for pH and ask, "What are the pH values of the various substances that could get into the water?". They need to learn what the numbers mean and what that, in turn, means for water quality. They then look back to their stream walk and begin to think about what organisms they observed and the possible impact substances with various pH levels could have on these organisms. They also look at land-use issues and their possible link to pH effects on the stream. For example, students recognize that people living in the condos may use fertilizer (one of the solutions they tested in their pH experiment) which may raise or lower the pH level and have harmful effects if it enters the water through run-off.

Students also use a conductivity probe to test for the amount of dissolved substances. Among other things this leads to concept development about the vital role nitrogen and phosphorous have for all living organisms and the negative effect of too much of these nutrients (resulting in eutrophication and dissolved oxygen depletion). Students test Sally's water (which is at a poor level) and ten to fifteen other water solutions. They also test a liter of water with three different amounts of salt that they have chosen to quantify just how little salt allows the water to remain excellent or good or drop to fair or poor according to standards. Students then begin to think about the stream and what dissolved substances may affect its

[4] We used the eMate by Apple Inc. Although the eMate is no longer available, other handhheld devices (the Palm™ and software by ImagiWorks and the Explorer by Pasco Scientific) that can be used with probes are currently on the market.

quality. They also begin to reflect on the season and its implications for various dissolved substances (e.g., salt in the winter or fertilizer in the spring).

In order that students gain experience and confidence with the technology, we initially introduced them to the probes by giving them step-by-step instructions, which they then applied to science activities. We subsequently realized that putting the focus on technology rather than on science and inquiry was a backwards approach to learning and to our technology goal of supporting and enhancing student scientists. So, the second year, we focused on the water concepts using activities that could be better understood with the use of these new portable technologies. In other words, we now introduce the water concepts with activities that simultaneously introduce the portable technology tools. As part of these activities students learn the procedural steps necessary to successfully use the portable technologies.

Although teacher-designed, these activities model good scientific inquiry. We use our role as teacher to carefully structure each experience so, through thoughtfully planned interactions with our students, they become co-designers of these activities. Through our questioning and discussion techniques, students learn to ask relevant questions, research information, and design and carry out experiments, including making predictions, writing simple procedures, creating data tables, and formulating analysis strategies. Once students have several experiences, we transition from teacher-designed activities to student-designed investigations. Students then take the lead in creating their own activities. We add support and give direction as needed. For example, we ask students to design and carry out simple experiments in the classroom that will provide them with insight about dissolved oxygen in water using the dissolved oxygen (DO) probe. This process includes obtaining background information to help both in the planning of the activity as well as the analysis of the results. Students ask questions, write simple procedures, and create data tables to investigate questions such as: Does fast or slow running water have more DO? How does this compare to still water? Does warm or cold water hold more DO? Can I increase the amount of DO if I stir the water?

Different groups design and carry out different investigations. Prior to conducting these activities students share their questions, procedures, and data tables with each other. They provide each other with feedback to help groups clarify their questions and improve their procedures and data tables. They also share their predictions and discuss how they will analyze the data. Often the student dialogue leads them to come up with more and better questions. Students also become excited and impressed hearing about other student experiments. After students conduct their experiments they share the results and discuss their meaning. Thinking back to their stream walk, where they look at stream flow, students can now begin to think about what parts

of the stream may have higher or lower levels of dissolved oxygen and why this might occur.

Table 2.1 summarizes some of the activities and includes both the concept goals and the technological goals.

Through the benchmark lessons students develop science concepts and learn science process in a collaborative framework. The technology serves as an essential component of the work. All of the examples in Table 2.1 illustrate how to embed portable technology in the curriculum in order to help students learn science concepts and carry out scientific investigations through inquiry. Students now have the tools, both cognitive and technical, to investigate our stream.

Investigating the stream

As discussed earlier, our goal centers on students making conclusions about the health of the stream through extended inquiry by collecting and analyzing stream data. Following two months of preparation our students

Table 2.1. How clean is the water behind our school? Benchmark lessons

Sub-question explored as benchmark lesson	**Concept goals**	**Technology goals**
1. How much water is on earth and how much of that is usable?	Water distribution, water use, conservation, water pollution	None
2. Where does the water come from?	Water cycle, renewable vs. non-renewable resource	None
3a. What substances can pollute the water? 3b. What effect do these substances have on water quality? 3c. How much is too much?	Water quality, water quality standards, water quality-effect on living organisms, water pollution • pH, acids, bases, neutralization • solutions: solute, solvent • thermal pollution • turbidity: density, suspended particles, erosion	Introduction to portable minicomputers • pH probe • conductivity probe • temperature probe
4. Is there enough oxygen to support life in the stream?	Dissolved oxygen	Dissolved oxygen probe
5. How do substances get into the water in the first place?	Water cycle, watershed, topography, point and non-point source pollution	None

are ready to conduct a comprehensive study of the stream. To help students take ownership of their work we have each group of two or three students adopt a portion of the stream. These portions are roughly ten meters in length.

Each student draws a rough scale model of his or her stream section. Partners choose three specific locations from which they will collect data. These locations are chosen using criteria such as stream flow, depth, width, plant life, etc. To illustrate the thoughtfulness with which students plan their data-collection procedures, we present two examples from student water-quality booklets (to be discussed in the next section). These students are not partners; they are also in two different classes.

Emily's procedure:

Each point we chose was very different from the others and that's why we chose them. Point A is pretty shallow, it is in a mixture of sun and shade. It is right under a waterfall, which is why it should be interesting to study, the D.O. level should be high, and the running water may affect the other tests too. Point B is in a sort of deep pocket, in the middle of the still part of the stream, the area around is sunny. Point C is another deep pocket, which is a small whirlpool. The water is moving quickly, however it is not splashing into the air. It may affect the D.O. Point C is mostly shady, but there is some sun. Each spot is unique and will have unique results.

Laura's procedure:

We picked three different spots to test in our part of the stream. Here is why we chose each particular one. Point A is before the waterfall, point B is right after the waterfall, and point C is a while after the waterfall. We picked point A because we wanted to see if it had less dissolved oxygen that point B, which is after the waterfall. We also wanted to compare the other tests to point B. It is pretty shallow, and the water is moving quickly because it is about to flow into the waterfall. We picked point B because otherwise, we couldn't compare point B to point A to see if falling water really does trap more oxygen. Around point B, the water is very deep, and is moving quickly because it has just come out of the waterfall. We picked point C to see how much the tests will change a while after the waterfall. The water is very shallow around point C, the bottom is sandy, and the water is very still.

Students spend three more days out at the stream collecting data. Students collaborate to gather both qualitative and quantitative data on their section. Using portable scientific laboratories (probes attached to handheld computers) our four seventh grade classes collect and analyze quantitative data by creating their own tables and graphs of temperature, dissolved oxygen, dissolved substances (conductivity), and pH. Students collect other qualitative and quantitative data including turbidity, stream flow, width, and depth. Table 2.2 is one example of a student data table of the water-quality tests.

When you include information such as the watershed, land use around

data labs/ posts.

Data Collection
November 11-13, 1997
Stream Section #6

Here are the results of our tests. Although we later took the averages of all the points, written here, is all of our data at points A, B, and C for pH, conductivity, temperature, dissolved oxygen (D.O.), and turbidity.

pH	Point A-#123	#1-7.81	#2-7.93	#3-7.91
pH				
pH	Point B-#123	#1-7.87	#2-7.90	#3-7.89
pH				
pH	Point C-#123	#1-8.15	#2-8.83	#3-8.14
Conductivity	Point A-#123	#1-586.47	#2-574.57	#3-582.22
Conductivity				
Conductivity	Point B-#123	#1-593.37	#2-590.18	#3-585.41
Conductivity				
Conductivity	Point C-#123	#1-591.24	#2-633.70	#3-591.78
Temperature	Point A-#123	#1-7.69	#2-7.69	#3-7.76
Temperature				
Temperature	Point B-#123	#1-7.84	#2-8.06	#3-7.98
Temperature				
Temperature	Point C-#123	#1-7.91	#2-7.91	#3-7.98
D.O.	Point A-#123	#1-7.71	#2-5.97	#3-7.12
D.O.				
D.O.	Point B-#123	#1-8.12	#2-7.53	#3-7.17
D.O.				
D.O.	Point C-#123	#1-8.65	#2-8.58	#3-7.27

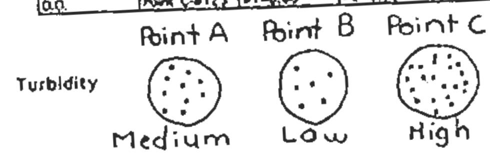

Table 2.2. Laura's data table of water quality tests.

the stream (condominiums, a freeway, a school, and roads nearby), and student observations at the stream, there is a large amount of information for students to analyze to make some decisions about the health of the stream.

Another important aspect of the investigation is that students collect data three times during the year: fall, winter, and spring. As they scatter data three times during the year: fall, winter, and spring. As they scatter along a stream and collect their stream data, students build on their classroom experiences that provides them with confidence and practice recognizing when a problem exists with the technology and how to problem-solve. They also know enough science and process so that the investigation is meaningful and important to them. They discuss information with each other, as scientists do, and share their findings.

Students analyze data by interpreting the results for each season based on concepts learned about water and water-quality standards. They work collaboratively during several class periods discussing their data to develop explanations of their findings. They look for patterns and relationships

Figure 2.4. Casey and Kelly collect winter water quality samples.

among factors for each season. Students share and discuss data from section to section, looking for consistencies and explanations for inconsistencies. Students also compare the data across the year as well. We are creating a database so that students can compare their data with data from past years and look for trends.

ASSESSING STUDENT UNDERSTANDING

We utilize a variety of assessment strategies to gain insights into our students' understanding of concepts and the process of inquiry. We discuss three of the assessment tools (water-quality booklets, concept maps, and pre- and post-tests) below.

Water-Quality Booklets

Each student creates a water-quality booklet of his or her stream section. These represent their understanding of water-quality concepts and science process through the stream investigation. In addition to classroom discussions we provide students with criteria sheets to guide them. We distribute these guideline sheets after students have generated and discussed ideas. This process helps us scaffold student learning of scientific inquiry.

Appendix A includes examples of guideline sheets for the stream drawing, a procedure for choosing test locations, prediction guidelines, the *Water Quality Booklet* guideline sheet, and various other sheets for data collection and analysis.

In each booklet, students place their questions on a title page along with other important information, such as their stream section, partner, and date of study. Each student personalizes the question so it becomes her or his own: "Is the Greenhills Creek Healthy?"; "Can I Drink out of the Greenhills Stream?"; "Is Our Stream Healthy?". This is followed by a section of background information on water quality that is written, section by section, as benchmark lessons are completed. After feedback from us, students revise their background information. Other sections include predictions for the overall health of the stream as well as individual water-quality measures, a stream drawing with three locations identified as sampling sites, justification for choosing each site (as stated in the procedure), data tables, observations, analysis, and conclusion. In the winter and spring students add predictions, data, and analysis. Below is an excerpt from a student's water-quality booklet of spring predictions and spring analysis:

> *Max's prediction:*
>
> In the temp. department we are looking for an abnormal amount of change or also known as thermal pollution. Thermal pollution can be caused by suspended particles and eutrophication. Since there are not any plants I wouldn't worry about eutrophication. Also the stream flow is very slow, so erosion will not occur quickly. If you ask me I would say there is not thermal pollution in the Greenhills stream. The only reason there may be a small change would be due to parts of the stream being in the sun and some parts in the shade. I say the temp. change will be between 0–2 degrees.
>
> *Max's analysis:*
>
> While doing the temperature testing we found some excellent results. The temp. changes from our section (6) and section 1 are at point A 0.14, B 0.05, and C 8.39. Points A and B are both differences of 0–2 degrees which is excellent water quality. Then, point C is between 5–9 degrees which is fair water quality. Points A and B seem to have no thermal pollution, but point C is questionable. Point C really isn't physically different from the other points, but this time of year point C is almost dried up and practically is just a small puddle. This has been caused because of the lack of rain in the recent weeks. As you know a small puddle on a rock (like point C is) normally exorbes heat and is hotter than the normal river. This may be the explanation for this outrageous number. In my predictions I predicted that there would be no thermal pollution, but that if there was any change it would be due to parts of the stream being in shade and other parts being in the sun. If this is true I would say I predicted right, and that there is no thermal pollution in the Greenhills stream.

In the above example, Max's prediction portrays an excellent understanding

of temperature testing to identify thermal pollution. He discusses causes of thermal pollution (erosion and euthrophication) and explains why he believes neither of these causes are present at this time. This leads to his prediction of a small temperature change. In his analysis he reports his results and their relationship to the water-quality standards, which show that two of the three sections indicate excellent water quality based on temperature (0–2 degrees temperature difference between his site and another one farther away). He sees that his third site, Location C, does indicate fair quality (8.39 degrees temperature change). He looks to his physical data, noticing that the water level is extremely low, to help him explain why. Max also ties in his predictions and concludes that there is no thermal pollution. He has shown that he understands thermal pollution. Perhaps just as important, Max has shown that he is able to look at data beyond the numbers the probes have provided; he is able to see a large difference in temperature and look to his other data to help make sense of his findings. His science process skills are evident.

As teachers, we find that the *Water Quality Booklet* illustrates the richness of student understanding as reflected in the presentation of various information and explanations. We see more in-depth understanding of the concepts as we move from season to season. Students are able to make more connections with background information and test results as well as draw on physical data and human activity related to the season.

Concept Maps

Concept maps are another assessment tool we utilize. Students draw pre- and post-concept maps (Novak & Gowin 1984) of their understanding of water quality. In his initial concept map (Figure 2.5, Devin presents a simple representation that illustrates water quality as how pure or polluted water may be. He has three subordinate concepts; however, these subordinate concepts represent the same ideas. He portrays a dramatic increase in his understanding of water quality through his final concept map (Figure 2.6). Here he includes the five water-quality tests of pH, conductivity, turbidity, temperature difference, and dissolved oxygen levels. He includes background concepts that provide insight into the in-depth understanding he has developed of the cause and consequences of differences in the tests.

Laura's initial concept map (Figure 2.7) represents a simple understanding of water quality as good or bad depending on temperature and pH. She has repeated concepts rather than drawn connections between concepts as she divides her ideas into the two categories of "good" or "bad." She continues to divide her ideas into sections by repeating concepts rather than making connections between ideas in her final concept map (Figure 2.8). However, the comparison of her final and initial concept maps depicts a

Figure 2.5. Devin's initial concept map of water quality

transition from a novice to a more expert understanding of water quality.

Laura's map, in particular, demonstrates a good understanding of the process of scientific investigation of water quality. For example, her map includes information about the data-collection tools for the water-quality tests (portable technology with probes), physical data and the information it provides, the scientific method of predictions, analysis, conclusions, and presentation of the ideas in a booklet. She also has information about the various water-quality tests.

Ben's initial concept map (Figure 2.9) illustrates another novice understanding of water quality. He also states on his paper that he has some experience with water quality. His final concept map (Figure 2.10), by contrast, illustrates a much richer understanding of water-quality tests and background, including point and non-point source pollution.

Looking at the maps one can see how these students have developed from novices in their first attempts to having richly developed concepts in their final attempts. Not only do concept maps provide us, as teachers, with valuable information, they also become a powerful visual documentation for students to see their own growth in developing in-depth understanding.

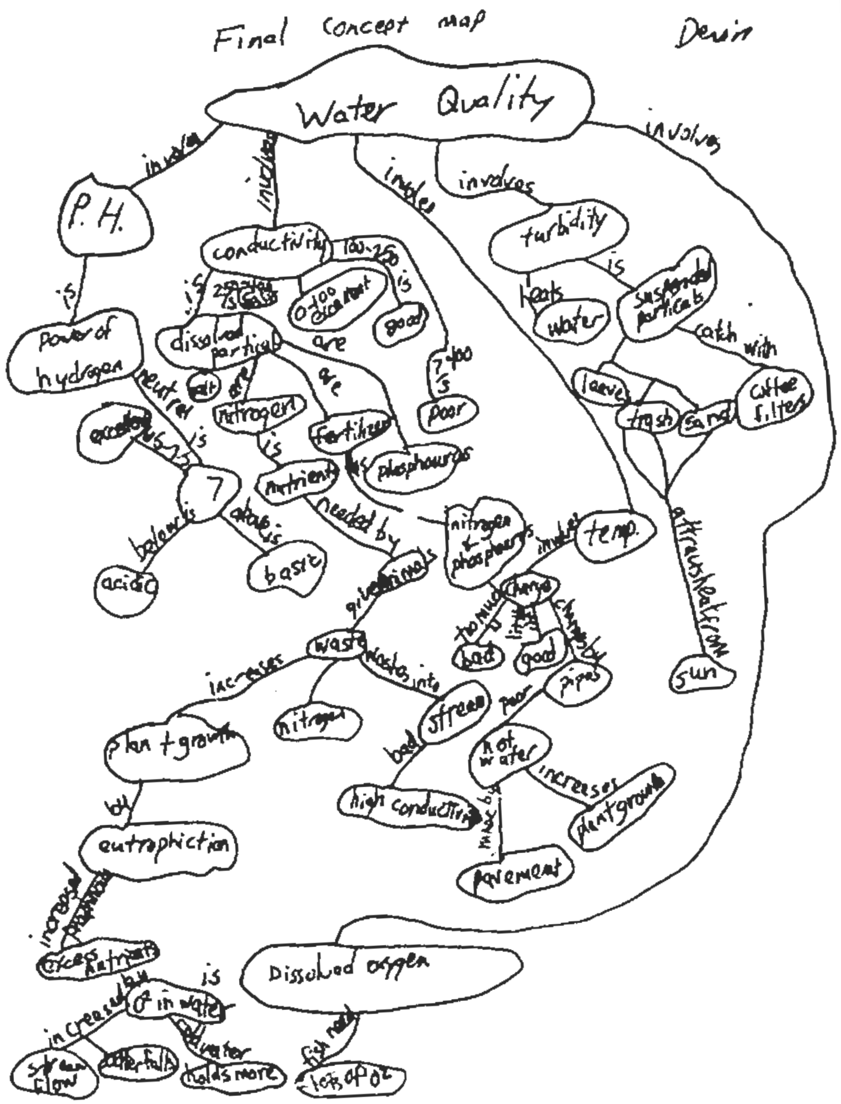

Figure 2.6. Devin's final concept map of water quality.

Pre- and Post-Tests

We also use pre-tests,[5] which show a student's initial understanding of water quality, and several post-tests. As discussed in Chapter 5, our students

[5] Test items were developed in conjunction with Krajcik and others at the University of Michigan.

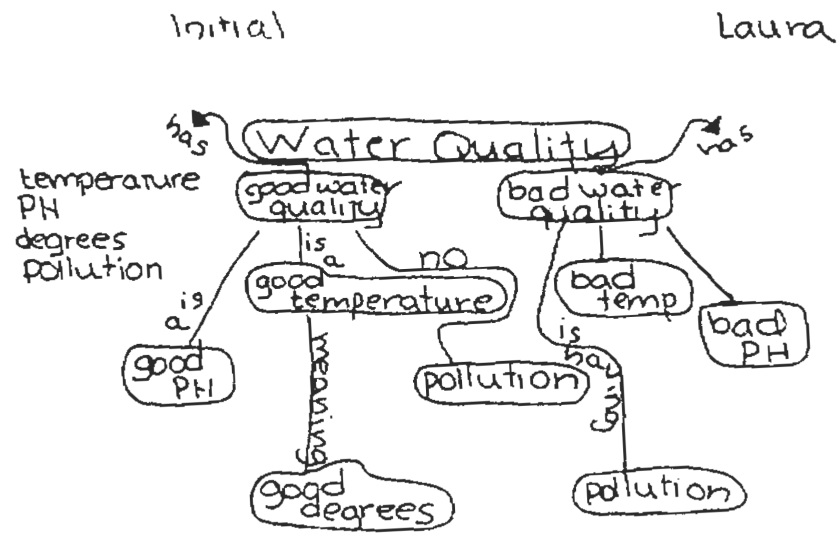

Figure 2.7. Laura's initial concept map of water quality.

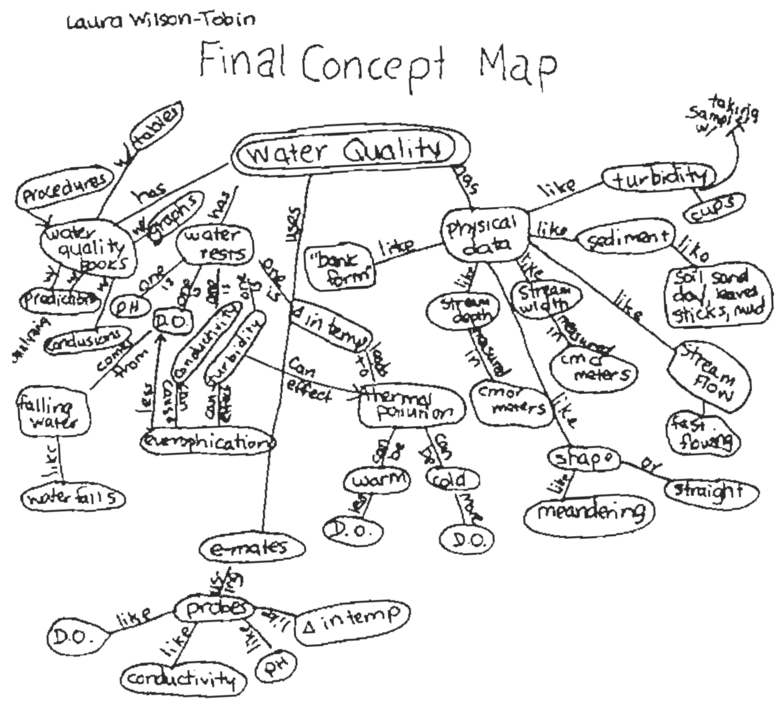

Figure 2.8. Laura's final concept map of water quality.

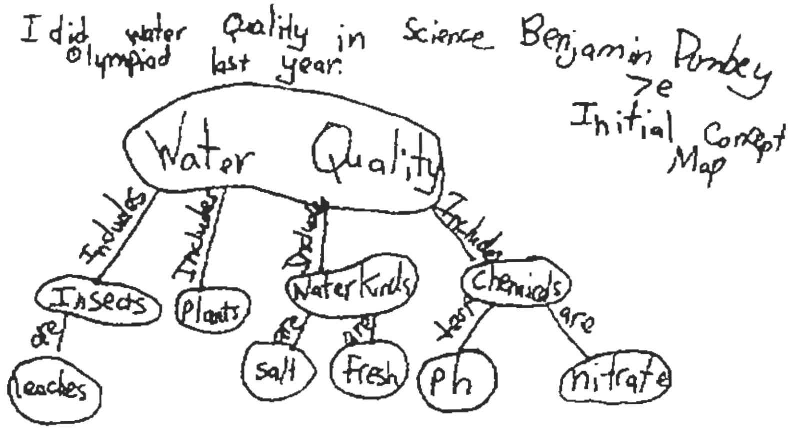

Figure 2.9. Ben's initial concept map of water quality

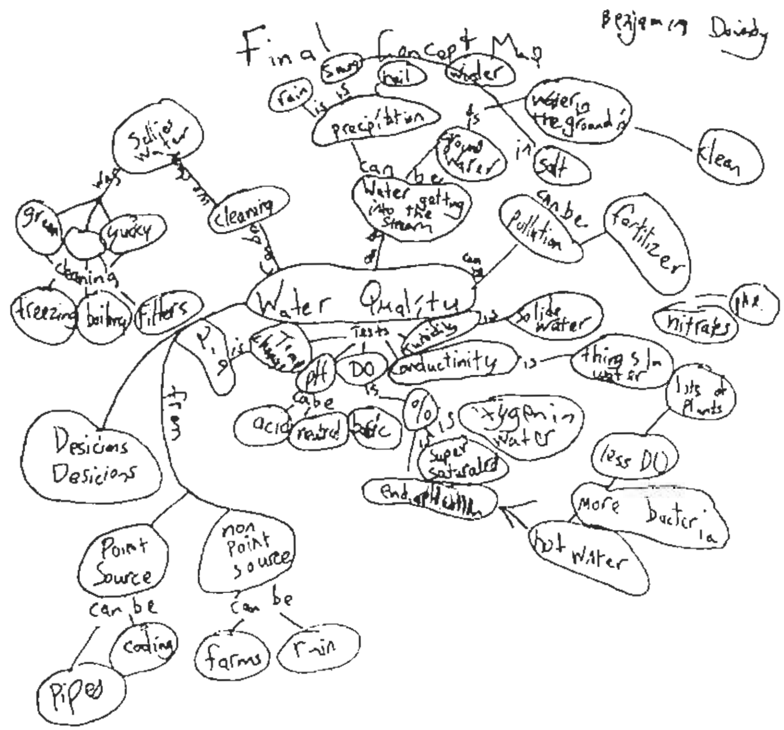

Figure 2.10. Ben's final concept map of water quality.

do substantially better in post-tests. We write many of our own tests, which include open-ended questions. They also include verbatim questions from the pre-tests. Students are presented with artificial stream data and asked to analyze the information and report results as well as make recommendations to a city mayor. Students compare their pre- and post-test answers, which again provides them with a concrete representation of how their explanations of events have moved from novice to richly developed.

All of these assessments provide us with valuable insights into the students' emerging understanding of water concepts and the process of inquiry. A more thorough discussion of water-quality booklets, concept maps, and tests can be found in Chapter 5.

DESIGN PRINCIPLES

Our water curriculum, as well as our entire program, reflects certain principles that we use extensively to design curriculum (Krajcik et al. 1998). In this section we highlight the major features that characterize our curriculum.

- *Contextualized*: Our curriculum provides students with phenomena in context. This includes taking students to the science, beyond the four walls of the classroom, when possible.
- *Driving questions*: These questions contextualize and bring meaning to learning. As students investigate these questions they develop in-depth and integrated understandings of concepts and process.
- *Benchmark lessons*: Students learn concepts, science process, and technology tools through benchmark lessons.
- *Extended inquiry*: Students are involved in long-term investigations, just as scientists are, to gain insight into their questions.
- *Teacher-structured to student-designed investigations*: We begin with a more tightly structured classroom and move to a more openly structured classroom by providing students with supports. These supports include careful layers of scaffolding which introduce and provide practice of the elements of good scientific inquiry.
- *Learning technologies*: We incorporate computer-based technology as a tool to support student inquiry when appropriate.
- *Multiple assessment of student learning*: We utilize a variety of assessment strategies including concept maps, pre- and post-tests with open-ended questions, artifacts such as booklets, multimedia projects, written lab reports, and student-created computer models.

In the following section, we describe the benefits for student learning afforded by the portable learning technology in the context of project-based science. We assess the benefits for our students from our observations of classroom activities, information from student work, consideration of classroom discussion, small group discussion and our experience as teachers.

BENEFITS OF TECHNOLOGY FOR STUDENT LEARNING

Our students have moved from simple word processing and playing games at home to tutorials and educational simulations at school. With the addition of portable technology, our students are now provided with scientific tools that empower them to collect and analyze data much like real scientists. We begin our discussion of the impact of technology in student learning with observations of students as scientists practicing good data collection and problem-solving techniques in our classrooms. Our students also learn the importance of calibrating and caring for their equipment. In the second section, we explore how these tools have helped our students become more invested in their data. In the final section, we examine how the use of technology tools in the field enables our students to develop a much richer understanding of water quality.

Students as Scientists

Where and how do our students collect meaningful data? What happens when students encounter problems with the technology in the field? How can students calibrate their tools to collect data correctly? Who will care for the tools? It is our goal to have our students learn science in the most meaningful way possible. By incorporating technology into our curriculum, our students are afforded an opportunity to learn science and practice sound science process skills just as scientists do each day.

Data Collection

One of our goals as teachers is to have our curriculum be a meaningful reflection of real life. Just as scientists have tools to collect data, our students have portable instruments that they take out into the field to gather data in real time to answer their questions. Students collect physical data to measure the depth, width, and length of the stream. They also record observations of stream flow and vegetation, which among other observations may influence and explain their chemical data. Technology not only provides students with the probes to collect specific data, it can store data, visualize data in tables, and graph data immediately. This allows students to

make initial interpretations of their results in the field where they can decide if the collection process needs to be repeated.

Another advantage in using specific probes to collect chemical data is that it eliminates the handling of harmful chemicals, which are contained in alternative methods such as the HOC chemical kits. For example, students can determine the dissolved oxygen levels at points along the stream by placing the DO and temperature probes in the water to determine the percent saturation using a scale. With proper maintenance these probes can be reused for a long time without calibration.

Before each collection, students make predictions for all three sections of their stream, for each test they complete. Students number, label, and record their data for three trials at each stream section and their observations. As students prepare to reflect on collected data, they take an average of the three trials. The collection of three trials allows students the opportunity to observe any discrepancies that may result as the probe is acclimating to a new location.

The design of the portable technology also allows students to practice good science process skills. Students can collect their data more efficiently and repeat any trials quickly if they encounter problems.

Problem Solving

Problems do occur when students use technology. These tools allow our students to develop a number of practical problem-solving skills. In the initial technology setup they develop the ability to detect problems and realize, on the spot, whether the data they have collected are accurate. Although many people believe solving hardware and software problems introduces unnecessary difficulties, we see it as a benefit to student learning. In the fall, students are novices at collecting data and become frustrated when they experience problems with the technology. In the winter, they have more confidence and become less frustrated with difficulties. By the spring they are completely proficient at recognizing and solving technology problems. The benchmark lessons used when introducing the probes assist students in recognizing the errors and learning to account for them in the field.

As our students become more confident in working with the technology, they look for solutions to the problems they encounter in the field before they call for our help. In the fall, students call for our help at the first sign of trouble. However, as they encounter data-collection problems during subsequent seasons, students begin to troubleshoot instrument malfunctions on their own. Students first check that all the components are properly and securely attached, e.g., serial interface box to computer, or probe to the interface box. Next, students double check if enough reserve battery power remains for them to complete their task in the field. Next, they move to the software setup to check for problems. Once they exhaust

all options they either call us or ask to use the portable technology of the group next to them.

We notice that as technology continues to advance, hardware and software equipment issues diminish. However, no matter how advanced the technology, potential issues with student use always arise.

Equipment Calibration and Care

Technology has provided us with an opportunity to introduce onr students to calibration. This science process skill frequently does not occur in the seventh grade curriculum; however, understanding calibration is an important skill highlighted in the AAAS (1993) *Benchmarks for Science Literacy*. Calibrating the pH, temperature, and conductivity probe offers students an opportunity to learn the meaning of two-point calibration and the need for standardizing all scientific equipment. Students learn that probes and instruments need to be calibrated to collect information and how one might calibrate an instrument so that it can collect accurate data.

Using probes requires care and maintenance. Just like scientists, our students learn that they must follow specific procedures to insure that probes and other hardware work in future projects. Students learn to place pH probes in a buffer solution of 4.0, insuring that the probe membranes do not dry out. Students also learn the importance of recharging portable technology overnight to prevent batteries from depleting in the field. Expecting students to care for equipment furthers their respect of the technology, which provides them the opportunity to learn in context.

Student Ownership of Data

Collecting field data helps our students gain ownership of their work, something we had not previously experienced. Because students view collected data as meaningful, they become invested in analyzing how the quality of their stream section compares to the others. We see evidence of this in the field and classroom when students ask the groups on either side to share their readings. They do this to check if their recorded values are consistent with their neighbors. If students find that their data differs from other groups, they desperately look for reasons to defend their data. On one occasion, students who were collecting data mid-stream noticed that their water temperature was several degrees cooler than the groups next to them. Because the technology allows students to immediately view and analyze the data they receive, the students thought that their data could be faulty. They first checked their equipment and then began to search for additional information that might explain this difference. Students began looking for pipes above and underground that could bring additional water to their part of the stream. After a few minutes, they uncovered a spout of cold water

flowing quickly from under the stream bank, which was concealed by a grassy over hang. They had not observed this in the previous field collection and noted that the depth of the water was lower now than before. They now felt that the data they had collected was accurate, and were pleased that they could support their findings. This increase in ownership of data engages students in interpreting data.

In-Depth Understanding of Water Quality

We have been greatly impressed by our students' growth in their ability to analyze and synthesize collected data. With each successive data collection, they demonstrate an improved ability to understand both the physical and chemical implications of their recorded data, yielding a more holistic, comprehensive picture of the stream under study. Collecting data in the field, as opposed to giving simulated data in the classroom, allows students to grasp the full range of dominant environmental factors and how these variables change over time.

In the fall, some students focus and report only on data recorded with the portable technology and often do not include their physical data, related observations, and information they obtained from benchmark lessons. In addition, some students do not attend to the quality of their data and are satisfied if their probes collect data, regardless of accuracy. These students do not detect their errors until they analyze the data in the classroom. Then, for example, they notice that they had recorded a water temperature of 68°C when the air temperature had been hovering at 20°C for several weeks. The students learn that they must pay careful attention to the accuracy of their data.

By winter our students develop a greater ability to make connections between their data and key environmental factors. Reflecting on both their quantitative and qualitative data, students begin to develop an understanding of the relationship between water quality and the controlling natural and human influences. One group of students showed concern about their dissolved oxygen readings, which were lower than the readings in the next stream section. They were convinced that they had collected and recorded the data correctly. In reviewing background information, they found that moving water could increase the amount of dissolved oxygen in the stream. They observed that in their section of the stream the water was very still while the section next to theirs had a slight drop in elevation, which caused the water to have a faster current. (Students refer to this slight drop in elevation as a slight waterfall.) Collecting data in the field enables students to reflect on their data as they observe firsthand the effects that environmental factors have on their stream.

In May, after collecting data over three seasons, students observe how common environmental factors impact the quality of the stream differently

during each season. In addition to seasonal analysis, students also analyze stream quality over the course of the year. When considering the conductivity data, students learn that while they may look at the water and see to the bottom, it may contain dissolved substances, which may cause problems for the health of their stream. In the fall students conclude that fertilized lawns in nearby condominiums cause high conductivity readings. When students consider reasons for higher conductivity readings in the winter than in the fall, they scrutinize their data. As they review their observations of physical data, students note an ice storm several days before the winter collection. With the ice storm comes the use of large quantities of salt on the roads, explaining the high levels of dissolved substances recorded by the conductivity probe. During the spring students conclude that lower levels of dissolved substances result from an increase in water depth, due to heavy rains experienced in recent weeks.

Learning about dissolved substances through reading books allows students to learn about conductivity. But when you combine reading with the experience of making observations, students make more solid connections between the environment they live in and the impact human activity has on it. Both allow students to learn. On the one hand, students remember the consequences of human activity on stream quality that they gather from books and class discussions. On the other hand, they also gain understanding by collecting data through the seasons and observing firsthand how common human activities influence water quality. Collecting stream data in the field is an incredibly powerful experience. It forces students to make connections between the concepts they discuss in class and the phenomena they experience when they collect data at the stream.

We notice an increase in our students' ability to analyze data in winter over fall, and in spring over winter, as well as a significant increase in their analytical skills in making connections to the real world. The water-quality booklets, which the students develop throughout the year, show progress towards a richer and more meaningful understanding of why our water resources are to be protected. Below are two partial examples of student analyses for fall, winter, and spring. For each season, students are given guidelines for what needs to be included in a good analysis (see Appendix A). We also provide students with feedback so that they can improve with each successive analysis. These examples demonstrate a wonderful progression in the development of data-analysis skills. The first example shows Emily's analysis based on temperature differences between two distant points along the stream. Temperature is an important measure because it provides information about thermal pollution. The second example is Gina's analysis of conductivity data to determine the quality of the stream based on the amount of dissolved substances.

Emily's fall water temperature analysis:

The temperature change at our stream ranged from 1.41–2.05 degrees Celsius. This is in the excellent and very high good range. This shows that there is little that changes our temperature. the difference probably has to do with basically shade verses sun. Point A had a temperature change of 1.41 degrees Celsius, this is an excellent temperature change range. Point B had a temperature change of 1.45 degrees Celsius, this is also excellent and excellent change. Point C had a temperature change of 2.05, which is good. Overall, most all animals should be able to survive in the stream.

In Emily's fall analysis she reports the data (her temperature subtracted from the farthest group's temperature to determine temperature differences). She also connects this data with the water-quality standards (excellent and good). She finishes her discussion about temperature by concluding that "most all animals should . . . survive."

Emily's winter water temperature analysis:

The temperature differences were excellent before, and they're even better now. Our temperatures were (in degrees Celcius) 7.26 at point A, 7.82 at point B, and 7.63 at point C. At point A we had a 0.88 degree difference over about a mile, which is great compared to the 1.41 degree difference we had in the fall. At point B we had a 0.18 degree difference, which is much better that the 1.45 degree difference we faced earlier in the year. Point C, however, was the big surprise, we dropped a 2.05 degree difference, good, (in the fall) down to an excellent .35 degree difference for the winter. I predicted that the temperature change would be excellent, and I was right. This is good, and it shows that there is definitely no thermal pollution.

In Emily's winter analysis we see, again, that she reports her data and makes connections to the standards. She also progresses to a higher level of analysis. In addition to her data and the standards, Emily also compares her results with her predictions and with the data she obtained in the fall. She decides, as well, that there is no thermal pollution. Emily's winter analysis shows much improvement over her fall analysis. Her highest level of analysis, though, comes in the spring.

Emily's spring water temperature analysis:

First we tested the temperature change. Point A had a change of 0.61 degrees Celsius, point B had a change of 1.02 degrees Celsius, and point C had a change of 0.94 degrees Celsius. All of these are excellent according to water quality standards. This shows that there is not thermal pollution, which is logical considering there are no factories around to dump, it hasn't rained much which could make rain that hit the pavement hot, and that rain could flow into the river and heat up the water. I predicted that the temperature change would be excellent or good (between 1 and 3), and I was right.

As in fall and winter, Emily reports her data and connects these to the standards. She also compares her predictions with her results. As in the

winter, Emily states that there is no thermal pollution. In addition, she supports her statement with plausible explanations (no factories to dump hot water, not much rain to be heated by pavement). She alludes to run-off (rain flow into the river).

When we look at Emily's analyses over the year for temperature differences, we see a progression from fall, winter, and spring that portrays an increase in her understanding of the concepts and the process of science. Each successive analysis reflects a richer understanding of water quality. The next example is another demonstration of a student's progression over the year. It focuses on the fact that there are different seasonal activities that may contribute to similar poor readings throughout the year.

Gina's fall conductivity analysis:

> Using the water quality standards, Anna and I found that the conductivity was poor because if you got the average of the three tests at each point you would have 574.02 for Point A. For point B you would have an average of 566.11. The average for point C was 523.16. If you add those together and divide by 3 you get 554.43. According to the water quality standards, that is poor [high] conductivity.[6]

In Gina's fall analysis for conductivity we see she simply reports the data she recorded in her data table and connects it to the water-quality standards to determine that it is poor quality. Her winter analysis shows a nice improvement.

Gina's winter conductivity analysis:

> The average of the conductivity was poor. For point A, the average was 581.21. For point B, the average was 590.87. For point C, the average was 547.24. These were all poor so the average was poor. This may have been because of salts from roads, nitrogen, and phosphorus. I predicted this would be fair but I was wrong. Last time, it was good [refers to the water quality and not the conductivity of the water]. This may have been because of more salt from the roads since it is winter.

Gina, again, reports the data and connects it to the standards (all poor according to the standards). This time, though, she attempts to provide an explanation for her results. She speculates about the many possible sources (salt, nitrogen, phosphorus) of these high readings without any regard to the season. High conductivity readings in the winter would most likely be due to salt from runoff. Phosphorus and nitrogen would most likely account for high conductivity readings in the fall and spring due to fertilizers. Decomposing matter might also account for high levels of nitrogen and phosphorus. Gina also compares her results with her predictions and with the data she obtained in the fall. Her winter analysis shows much

[6] Conductivity, measures the amount of dissolved substances. High conductivity implies poor water quality.

Table 2.3. Examples of seventh grade curriculum with embedded technology

7th Grade driving questions	Technology/probes used	Examples of investigations
How clean is the water in the stream behind our school? (Yearlong study)	DO, pH, temperature, conductivity, Model-It computer program.	To check water quality and determine the stream's: pH, temperature, conductivity and dissolved oxygen.
Where does our garbage go?	Temperature, pH.	Determine if pH affects the rate of decomposition and if temperature variations are found within the compost environment.

improvement over her fall analysis. But Gina's highest level of analysis comes in the spring.

Gina's spring conductivity analysis:

> Our conductivity was high. The average of our whole stream section was 588.05. This is in the poor range. This is probably this low because it is spring and many people are using fertilizer in their gardens. The fertilizer could have run-off the gardens after the rainstorm we had last week. This would have raised the conductivity level. Since the stream is by some condos with little gardens outside, this is very possible. I predicted that the conductivity would be high because of the fertilizer and I was right

In her spring analysis Gina reports her data and connects it to the standards (again, poor readings). This time she provides a plausible explanation of these high, poor readings (it is spring: people using fertilizer). She further supports her explanation by adding how fertilizer enters the stream through run-off. She nicely connects her physical data (recent weather: it has just rained). She ties both of these to human activities in a nearby condominium. Gina ends her analysis by comparing her results with her predictions.

Gina's analyses over the year is another documentation of how our students develop rich understandings over time. They engage in inquiry through long-term investigation and collaboration with others of meaningful questions. They are able to collect data in the field, reflect on that data with their peers, and are provided with feedback from us. In the process they develop an in-depth and integrated understanding of science concepts and process skills.

BENEFITS AND CHALLENGES OF USING TECHNOLOGY FOR TEACHERS

We begin by discussing how the infusion of portable tools has enriched our teaching experiences both in and out of the classroom. As teachers, what

environment have we created that allows us to realize one of our goals, which is to support our students in their quest to develop long-term investigations? How often can we provide opportunities for our students to use portable technology? Can portable technology move the science learning beyond the classroom walls? How have we as teachers grown through this experience? What have we done to share the excitement we feel about our classes? After we reflect on these questions, we discuss the challenges teachers face when incorporating new tools into their curriculum: Who will teach the students to use our new tools? Who takes care of the tools? How do I keep track of all this equipment?

Benefits for Teachers of Using Technology

Technology provides many benefits for teachers. First, portable technology has made class more exciting, and it allows us to address and meet many of the national science teaching goals. One of these goals calls on students to be involved in long-term investigations. The use of portable learning technologies has allowed us to create a classroom where students look forward to designing experiments to answer "what if" questions they ask during our class discussions. Portable technology tools have increased their options for designing experiments to collect quantitative data. For example, in an 8th grade project on digestion, to explore the effect different brands of antacids have on gastric juices, we previously gave students pH paper to take several readings throughout the day in an attempt to record significant changes throughout the experiment. Now, with the pH probe connected to laptops, students can collect data in real time for several hours. By incorporating portable technology, we can now engage our students in designing more thoughtful, long-term investigations.

Second, these tools move our classes beyond the four walls of the classroom to where science is happening. Whether our students study water-quality data in the stream or weather outside of the classroom, they collect data in context with probes allowing them to observe firsthand a variety of phenomena. In one instance, eighth grade students study weather by using the barometric pressure, relative humidity, and temperature probes to predict the day's weather and compare it to the forecast for the area on the Internet. Through this experience students gain an appreciation of the variety of data that needs to be collected to forecast the weather and what those factors may feel and look like, for example, "What conditions are present when a storm is approaching?" and "How does it feel?". In addition, they learn that their instruments are capable of recording data as accurate as the information that is recorded by sophisticated scientific equipment.

A third benefit of portable technology is that it allows us the opportunity to provide a variety of experiences that were not possible without portable technology. Throughout this chapter we describe the use of

technology in our study of water quality within the seventh grade curriculum. While we do not detail all of our uses, we outline, in Tables 2.3 and 2.4, examples of how we have incorporated these tools into our seventh and eighth grade curriculum.

Fourth, using portable technology also challenges us to learn with our students. Learning to use portable technology increases our depth of understanding of the technology and the concepts we teach. The water-quality project, for example, increased our awareness of the importance of qualitative data and its impact on the analysis of quantitative data.

Finally, the opportunity to work with these tools and to study how our students have benefited from this experience presents us with the opportunity to talk with our peers about our observations. We have had the opportunity to present our work at the National Science Teachers Association, Association of Independent Middle Schools, and National Association for Research in Science Teaching conferences and engage in conversations with other teachers and researchers about the benefits and challenges of infusing portable technology into the science curriculum. We have embraced the opportunity for this professional development and continue to share and dialogue with others as they prepare to enhance their curriculums with technology.

Challenges of Using Technology for Teachers

When teachers commit themselves to the task of infusing technology into the classroom they should understand that time seems to be a recurring theme. Below we discuss the most pressing issues of using technology in our classrooms.

Table 2.4. Examples of eighth grade curriculum with embedded technology

8th Grade driving questions	Technology/probes used	Example investigations
How accurately can you predict the weather?	Temperature, barometric pressure, relative humidity, Internet	Analyze how various physical phenomena interact to give us our weather by using probes to collect data and compare it to the Internet weather reports.
Where do plants get their energy?	DO, CO_2 pressure, temperature	Determine if DO production changes when plants are placed in light vs. no light.
Where do you get your energy?	pH	Students design experiments to determine the effect antacids have on gastric juices.

First, time is an issue in learning to use the technology and in implementing technology into the curriculum. To ensure successful use of technology in the classroom, it is imperative that teachers realize the initial time commitment it takes to learn how to use the equipment confidently. Workshops help teachers prepare to use the equipment. However, workshops are not enough. Teachers need to try it all out on their own to build confidence before they provide the experience for their students.

Second, the ongoing management of materials presents another major challenge. Assigning equipment to students and keeping track of the various types and amount of equipment requires detailed record keeping. We mark and label all equipment into sets and store it in a safe and secure place. When students prepare to collect data, students learn to match the labels on the equipment to ensure the proper probe is attached to the corresponding computer to which it is calibrated. This also requires time.

Next, as students prepare to collect stream data, time is needed to prepare all the equipment. While students learn to calibrate and take care of many of the probes, certain probes require more care and involve harmful solutions. The dissolved oxygen probe, for example, takes extra time to calibrate because of the procedure involved and the chemicals used. To ensure that data collection in the field is successful, we prepare extra equipment in case a probe, computer, battery or serial box fails in the field.

Fourth, it also takes time to teach the students expectations for use and care of the equipment. Students need to learn how equipment is turned off, how to store probes and equipment. When students collect data they must learn how to leave the equipment ready to be used by the next class.

Finally, teachers must constantly check that all equipment works. They also need to keep up-to-date with the latest innovations. As old equipment wears out it is important to gradually replace it with better technology before it becomes a financial burden down the line.

CONCLUSIONS

Over the past couple of years our students have experienced cutting-edge technologies that provide a glimpse of tomorrow's science classrooms and what their work world will look like. Our work has shown that portable technology allows students to *do* science. These new learning technologies enhance the science experience of students by allowing them to experience science in context. Students now view science as an important part of their everyday lives.

Portable technology also puts scientific tools that are similar to those scientists use in students' hands. Students now have more opportunities to design and carry out meaningful investigations and to answer questions posed by teachers and by their own "what if questions." Not only do these investigations engage students in the science process, they result in students developing in-depth understanding of science concepts.

These tools provide students with more opportunities to understand concepts such as calibration and to problem-solve, just as scientists do, when data-collection issues arise.

Students show excitement about the work that they do using portable technology. We see evidence of this in their strong ownership of their data. They develop explanations of their data by making connections to science concepts.

Incorporating portable technology tools has several implications for curriculum. First, because the technology is portable it moves the world of science out to the field. It enables teachers to use curriculum that goes beyond the four walls of the classroom to where actual science happens. Students now see the reasons for doing science.

Second, these technologies increase the possibilities of curriculum design because they provide students with scientific instruments to collect data in real time. These portable technologies become integral tools that help students develop stronger understandings of science content and process skills because learners can do activities that they could not do otherwise.

Finally, implications for curriculum designers exist, be they teachers themselves or designers of commercially available curriculum. We believe that technology tools should be created and implemented from the start rather than after the curriculum is already in place. But teachers who have been working for several years do not have this luxury. These teachers have already implemented a pre-high-technology curriculum. They need to examine existing curriculums to determine where technology tools will enhance student learning. Then they need to incorporate these tools by redesigning existing curriculum.

In a project-based classroom such as ours, students actively learn. Infusion of portable technology into our curriculum has had an immensely positive effect on the growth of our students' scientific understanding of concepts and process and has given new meaning to the term "active learner." Students find investigating the stream quality to be important and meaningful. In other words, rather than just learning about science, the water project enables our students to be real scientists doing real science (Krajcik 1993).

REFERENCES

American Association for the Advancement of Science. 1993. *Benchmarks for Science Literacy*. New York: Oxford University Press.

Blumenfeld, P.C., E. Soloway, R. Marx, J.S. Krajcik, M. Guzdial, and A. Palincsar. 1991. "Motivating project-based learning: Sustaining the doing, supporting the learning," *Educational Psychologist*, 26(3/4):369–398.

Cromwell, M., E. Delhagen, J. Hartman, R. Reese, and M. Zweiziz. 1992. *Water Studies for Younger Folks: A Water Activities Manual for 5th through 8th Grades*. The Global Rivers Environmental Education Network. Earthforce 1908 Mount Vernon Avenue, Alexandria, VA 22301.

Krajcik, J.S. 1993. "Learning science by doing science" in R. Yager, ed., *What Research Says to the Science Teacher: Science, Society and Technology*. Washington, DC: National Science Teacher Association.

Krajcik, J., B. Blumenfeld, R. Marx, and E. Soloway. 1999. "Instructional, curricular, and technological supports for inquiry in science classrooms" in J. Minstell and E. Van Zee, eds., *Inquiry into Inquiry: Science Learning and Teaching*. Washington, DC: American Association for the Advancement of Science Press.

Krajcik, J.S., P. Blumenfeld, R.W. Marx, K.M. Bass, J. Fredricks, and E. Soloway. 1998. "Middle school students' initial attempts at inquiry in project-based science classrooms," *Journal of the Learning Sciences*. Vol. 7 Issue 3 and 4 pps 313–350.

Krajcik, J.S., C. Czerniak, and C. Berger. 1998. *Teaching Children Science: A Project-Based Approach*. Boston: McGraw-Hill.

National Research Council. 1996. *National Science Education Standards*. Washington, DC: National Academy Press.

Novak, J.D. and D.B. Gowin. 1984. *Learning How to Learn*. Cambridge: Cambridge University Press.

Stapp, W.B. and M. Mitchell. 1995. *Field Manual for Global Low-Cost Water Quality Monitoring*. The Global Rivers Environmental Education Network. Thomson Shore Printers, 7300 Joy Road, Dexter, Michigan 48130.

CHAPTER 3

Case Study at Mount Baker High School

David Tucker

INTRODUCTION

This is a story about how one teacher utilized technology-intensive project-based instructional methods that allow students to design their own learning directions. It is a story about students learning to apply higher-order thinking and action processes in their quest to care for their environment. Lastly, it is a story about students experiencing the rewards and pitfalls of becoming active learners.

The *National Science Education Standards* state that science educators must improve instructional methods "to enhance students' learning skills so that they will be better able to cope in a rapidly changing technological society." The standards suggest teachers implement **active learning strategies** designed to improve science achievement. In summary, the standards emphatically state that science teachers must provide classroom opportunities for students to **do science**.

This chapter will describe how the Mount Baker High School project-

David Tucker, Mount Baker High School

Portable Technologies: Science Learning in Context, edited by Tinker and Krajcik. Kluwer Academic/Plenum Publishers, New York, 2001.